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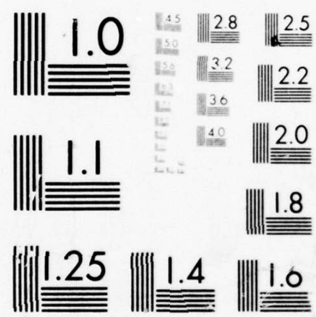

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STABILITY TESTS OF NAWILIWILI BREAKWATER REPAIR

by

D. Donald Davidson

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

January 1978

Final Report

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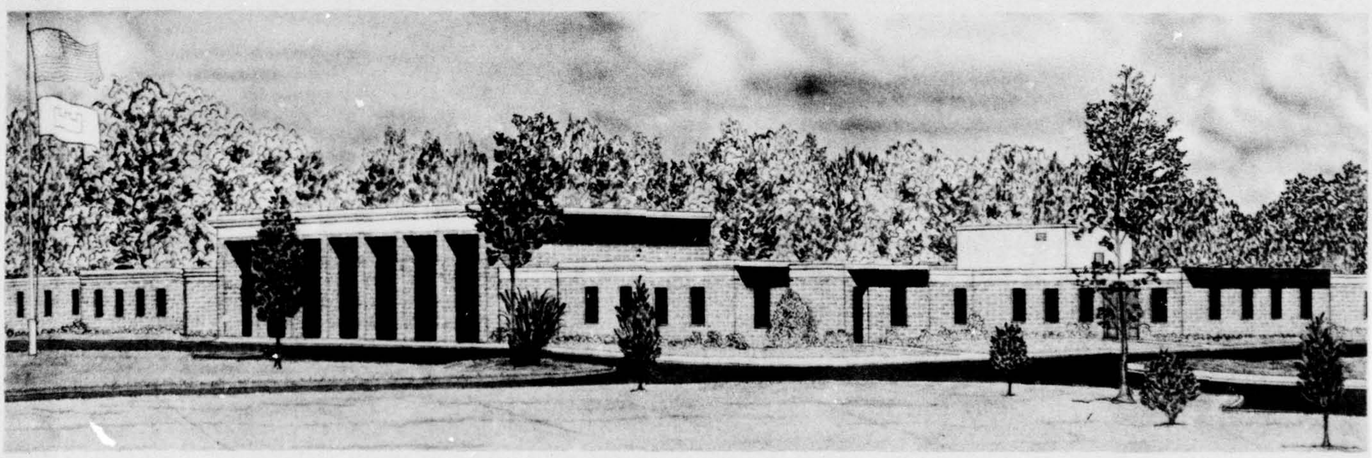

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Undistorted-scale hydraulic model tests (1:30.5) were conducted to investigate the adequacy of dolos repair sections considered for use on the Nawiliwili breakwater, Island of Kauai, Hawaii. Test sections 1 and 1A were considered for repair to breakwater sta 15+00 to 20+00 and test sections 2 and 3 were considered for sta 12+00 to 15+00 and 5+00 to 12+00, respectively. Results of the tests indicated that all of the repair sections tested are of adequate stability for the test conditions and locations for which they were tested.

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Preface

The model investigation reported herein was requested by the U. S. Army Engineer Division, Pacific Ocean (POD), in a letter to the U. S. Army Engineer Waterways Experiment Station (WES) dated 20 July 1976. The investigation was authorized by POD Intra-Army Order PODSP-CIV-76T-34 dated 20 July 1976.

Model tests were conducted at WES during the period August to September 1976 under the general direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Dr. R. W. Whalin, Chief of the Wave Dynamics Division. The tests were conducted by Mr. D. D. Davidson, Chief of the Wave Research Branch, assisted by Mr. W. Dubose, Engineering Technician. This report was prepared by Mr. Davidson.

Liaison between POD and WES was maintained during the course of the investigation by telephone communications and progress reports.

Director of WES during this investigation and the preparation and publication of this report was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

Contents

Conversion Factors, U. S. Customary to Metric (SI) Units of Measurement

U. S. Customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
pounds (mass)	0.4535924	kilograms
tons (2000 lb, mass)	907.1847	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

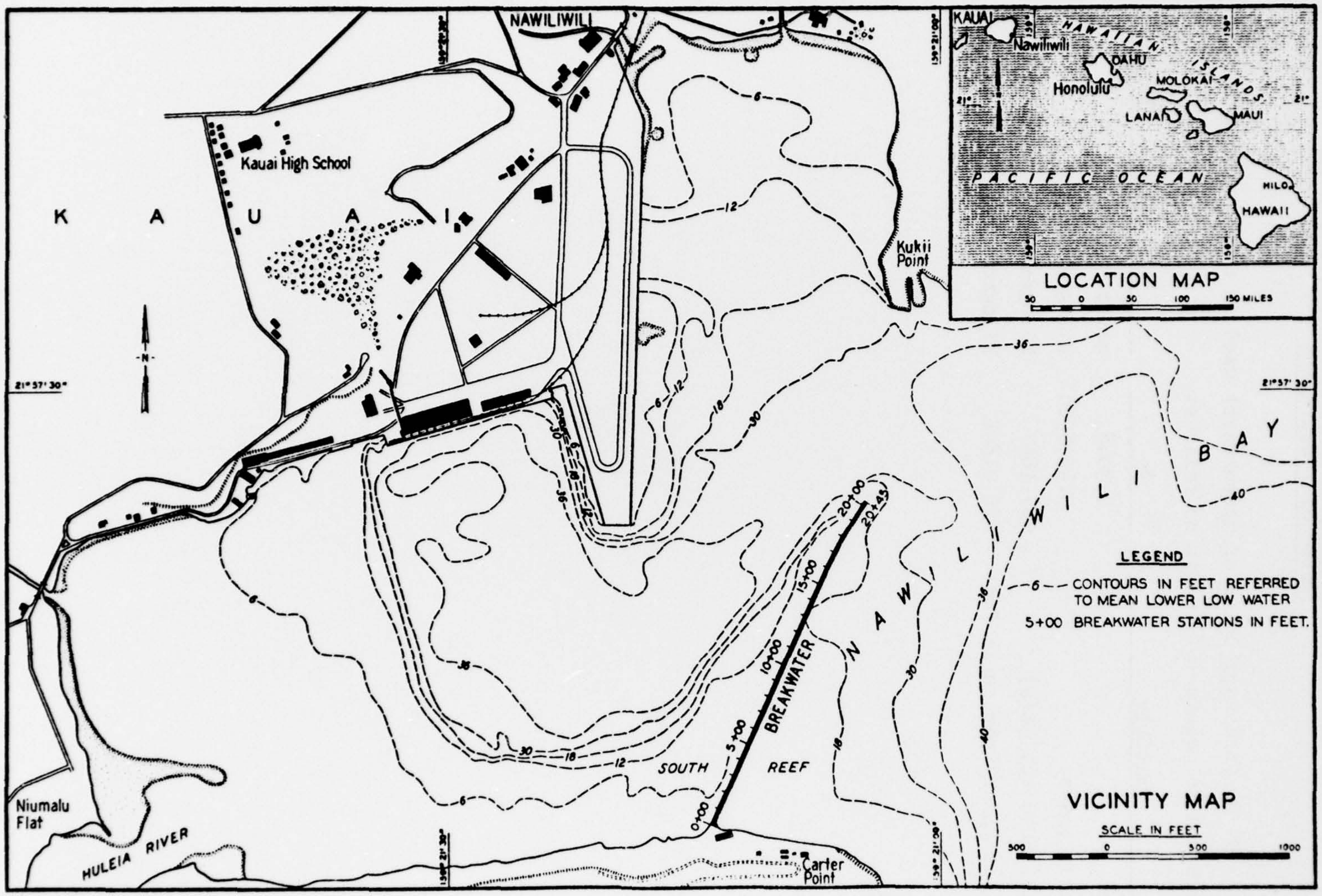

Figure 1. Location and vicinity map

STABILITY TESTS OF NAWILIWILI BREAKWATER REPAIR

Hydraulic Model Investigation

Introduction

1. Nawiliwili Harbor is located on the southeast coast of the Island of Kauai, Hawaii (Figure 1). It is the primary harbor for Kauai and is protected from the ocean environment by a single rubble-mound breakwater extending along the south reef for approximately 2045 ft.* Various sections of the breakwater have been severely damaged over the years and repaired with either stone or tribar armor. One such repair consists of one layer of uniformly placed 17.8-ton tribars from approximately sta 15+00 to 20+00. Armor of shoreward sections consists of 8- to 10-ton stone. During general reconnaissance of the breakwater in 1975, general deterioration of stone armor was noted from about sta 5+00 to 15+00 and several slumped areas along the uniformly placed tribars resulted in some breakage of the upslope units. Upon detailed inspection, it was discovered that a considerable portion of the tribar toe units was broken and had been displaced in the slumped areas; thus it was necessary to initiate repairs to the toe of the breakwater to prevent further deterioration.

2. Some of the repair sections proposed by the U. S. Army Engineer Division, South Pacific (POD), consist of dolosse placed over the existing tribar toe or, as in the case of shoreward sections, over existing stone armor. Since there are limited design data for dolosse in breaking wave conditions, since the crown elevation of the Nawiliwili breakwater is such that the structure can be overtopped by the selected design wave, and since the water depth at the toe of the breakwater is such that waves of height equal to or slightly less than the design wave will break directly on the structure, it was concluded that model

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

tests were necessary to assure an adequate repair section.

Purpose of Model Study

3. The model study was conducted to investigate the adequacy of breakwater repair sections proposed by POD for the Nawiliwili breakwater. Specifically, it was desired to determine the stability of the proposed repair sections when attacked by the largest breaking waves which may occur in that area and to assure that a significant number of the dolosse used in the repair did not move about when exposed to storm waves.

Design of Model

4. Tests were conducted at an undistorted linear scale of 1:30.5, model to prototype. Scale selection was based on the size of model armor units available for reproduction of the proposed and existing armor units, the preclusion of stability scale effects, capabilities of the available wave generator, and depth of water at the toe of the breakwater. This model scale, as are those for all breakwater stability models, was necessarily based on Froude scaling relations in which gravitational force is predominate.* However, to assure no viscous force scale effect on stability, the scaling also was checked for a proper no-scale-effect Reynolds number scaling.** At the scale selected for this study, model sizing of the prototype units involved did not show any scale effects. Based on Froude's model law and a linear scale of 1:30.5, the following model-to-prototype relations were derived:

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* J. C. Stevens et al., "Hydraulic Models," Manuals of Engineering Practice No. 25, 1942, American Society of Civil Engineers, New York.

** R. Y. Hudson and D. D. Davidson, "Reliability of Rubble-Mound Breakwater Stability Models," Proceedings, Symposium on Modeling Techniques, San Francisco, Calif., American Society of Civil Engineers, Vol II, Sep 1975, pp 1603-1622.

Characteristic	Dimension*	Model:Prototype Scale Relation
Length	L	$L_r = 1:30.5$
Area	L^2	$A_r = L_r^2 = 930.25$
Volume	L^3	$V_r = L_r^3 = 1:28,373$
Time	T	$T_r = L_r^{1/2} = 1:5.53$

5. The specific weight of water used in the model was assumed to be 62.4 pcf and that of seawater 64.0 pcf. The specific weights of model breakwater construction materials were not the same as their prototype counterparts. These variables were related using the following transference equation**:

$$\frac{(W_r)_m}{(W_r)_p} = \frac{(\gamma_r)_m}{(\gamma_r)_p}\left(\frac{L_m}{L_p}\right)^3\left[\frac{(S_r)_p - 1}{(S_r)_m - 1}\right]^3$$

where

subscripts m and p = model and prototype quantities, respectively

W_r = weight of an individual armor unit or rock, lb

γ_r = specific weight of an individual armor unit or rock, pcf

L_m/L_p = linear scale of the model

S_r = specific gravity of an individual armor unit or rock relative to the water in which the breakwater is constructed, i.e., $S_r = \gamma_r/\gamma_w$, where γ_w is the specific weight of water, pcf

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* Dimensions are in terms of length (L) and time (T). For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix A).

** U. S. Army Engineer Waterways Experiment Station, CE, "Empirical Verification of Transference Equations in Laboratory Study of Breakwater Stability," Bulletin No. 31, Apr 1948, Vicksburg, Miss.

Test Equipment and Procedures

6. Tests were conducted in a 5-ft-wide, 4-ft-deep, and 119-ft-long concrete flume in which the breakwater sections were installed about 90 ft from the wave generator. The flume was equipped with a vertical-displacement, variable-speed wave generator capable of producing sinusoidal waves of various periods and heights. A 1V-on-10H bottom slope was molded in the study area of the flume to simulate the immediate prototype bathymetry (Plate 1). During wave calibration, changes in water-surface elevation as a function of time were measured by electrical wave-height gages and recorded on chart paper by an electrically operated oscillograph. The electrical output of each wave gage was directly proportional to its submergence depth.

7. All model breakwater sections were constructed to reproduce as closely as possible the existing prototype breakwater. The core material was shoveled into the flume and shaped and compacted by hand trowels to simulate natural consolidation resulting from wave action. Any addition of stone proposed for filler in the prototype was added by shovel and smoothed to grade by hand with no compaction pressure applied. Placement of the existing tribar and stone armor was uniform as instructed by POD. Placement of the proposed dolos armor was random except for the tow units which were generally placed with their vertical fluke seaward. The thickness of the cover layers and the number of armor units required per unit area of cover layer used in this study can be calculated using the following equations:

$$t = nk_{\Delta}\left(\frac{W_r}{\gamma_r}\right)^{1/3}$$

$$\frac{N_r}{A} = nk_{\Delta}\left(1 - P\right)\left(\frac{\gamma_r}{W_r}\right)^{2/3}$$

where

t = thickness of n layers of armor units of weight, W_r, and specific weight, γ_r

k_Δ = experimentally determined coefficient that is a function of the shape of the armor unit and the method of placement

N_r = required number of armor units for a given surface area

P = porosity of the cover layers, percent

Presently used values of k_Δ and P, which were determined experimentally by a limited number of small-scale armor unit tests prior to this study, are 1.0 and 63 percent, respectively.

8. For each test, the stability of the armor units was assessed by visual observation during the conduct of the wave action. Photographs of the test sections were made before, during, and after exposure to the selected wave conditions.

Tests and Results

9. The adequacy of four potential repair sections was investigated by means of two-dimensional stability tests. Stability tests of test sections 1 and 1A were conducted for potential repairs from breakwater sta 15+00 to 20+00 while test sections 2 and 3 were applicable to sta 12+00 to 15+00 and sta 5+00 to 12+00, respectively. It was desired by POD that the various test sections be stable for the worst breaking 12- and 16-sec waves that could occur on the breakwater for the selected still-water levels (swl's) of +3.5 ft mllw and -0.5 ft mllw. Test sections 1 and 1A, tested for repair plans in the deepest water, were checked for both high and low swl's with a bottom elevation of -15 ft mllw, while test sections 2 and 3 were tested only for the high-water level with a bottom elevation of -6.5 ft mllw.

10. The breakwater sections tested, specific test conditions, and test results were as follows:

Test section 1

11. A cross section of the proposed repair section is shown in Plate 2 and in before-testing Photos 1 and 2. The seaward bottom toe

elevation of the typical section was -15 ft mllw and the crown elevation was +13 ft mllw. The one layer of 8- to 10-ton armor stone was placed and, along with the core material, formed an almost impervious barrier. The one layer of tribars was specially placed with all legs normal to the breakwater slope except for several of the toe units which were broken to simulate existing prototype damage. The general placement of the dolosse in the seaward toe was with the vertical fluke seaward, while the remaining dolosse were randomly placed two layers thick and then tapered into one layer with a top elevation of about +5 ft mllw.

12. Selected test conditions consist of the worst breaking 12- and 16-sec waves that could occur on the structure at swl's of +3.5 ft mllw and -5 ft mllw. Based on a procedure in which a selected wave period was set on the wave generator for a given swl and the wave height "tuned" until the worst breaking wave was observed, the following worst breaking wave conditions on the structure were recorded:

Still-Water Level ft mllw	Wave Period, T sec	Wave Height, H ft
+3.5	12	19.4
	16	16.9
-5.0	12	8.4
	16	8.9

In general, there was not a great deal of difference in the severity of the 12- and 16-sec waves at the respective swl's, although it seemed that the 16-sec wave at the +3.5 ft mllw swl and the 12-sec wave at the -5 ft mllw swl had more effect on the mound of dolosse.

13. The repair section was tested twice--the first time starting with the +3.5 ft mllw swl and then a repeat test starting with the -5 ft mllw swl. Each test was conducted for a total prototype time of at least 1 hr per wave condition, but it was observed that the test section had stabilized (no progressive or additional movement of dolosse) for each selected test condition within about 30 min prototype time. During the first test, the overall repair section was stable with no more than 6 dolosse (out of a total of 155 dolosse in the test sections) moving; 5 of these dolosse rocked gently in place while 1 dolos "flip-flopped"

to find a better nesting position. Photos 3 and 4 show the section after testing with the 16-sec, 16.9-ft wave at the +3.5 ft mllw swl. The repeat test (starting at -5 ft mllw swl) had very little dolos movement (only one) for the 16-sec wave; however, five dolosse rocked in place with the 12-sec wave. There was no dolos displacement at the -5 ft mllw swl. Photo 5 shows the section after testing with the 16-sec wave followed by the 12-sec wave at the -5 ft mllw swl. At the +3.5 ft mllw swl of the repeat test, four additional dolosse rocked slightly in place to find a better nesting position. Photo 6 shows the test section after accumulative testing of both the 12- and 16-sec waves at the -5 ft mllw swl and +3.5 mllw swl, respectively. Even though a slight in-place rocking of a limited number of dolosse took place in both tests, it is our opinion that only one dolos per test moved sufficiently to cause breakage. Unraveling of the dolosse into the tribars at the transition level was not observed during either of the tests.

Test section 1A

14. Tests of test section 1A (Plate 2) were conducted to see if the top elevation of the dolosse slope in test section 1 (+5 ft mllw) could be lowered to 0.0 ft mllw and still provide the same stability. The test section was subjected to the worst breaking wave conditions of 12-sec, 8.4-ft and 16-sec, 8.9-ft waves at the -5 ft mllw swl for a total prototype time of 1 hr; and then to 12-sec, 19.5-ft and 16-sec, 16.9-ft waves at the +3.5 ft mllw swl for another prototype hour. Test section 1A (after testing, Photo 7) was stable for the -5 ft mllw swl, and observations indicated that no more than 4 dolosse (out of a total of 132 in the test section) rocked in place. During continuation of the test through the +3.5 ft mllw swl, two dolosse were unnested, and a total of six dolosse rocked in place. Final conclusions were that the overall repair section was stable with no major damage (Photo 8).

Test sections 2 and 3

15. Test sections 2 and 3 (Plates 3 and 4) are typical shoreward sections selected for testing from sta 12+00 to 15+00 and sta 5+00 to 12+00, respectively. Both of these test sections were tested for 1-hr prototype time for each of the worst breaking 12- and 16-sec wave

conditions using a bottom elevation at the toe of the test section of -6.5 ft mllw and a swl of +3.5 ft mllw. This swl and bottom elevation result in the same worst wave condition as the -5 ft mllw swl and -15 ft mllw bottom elevation conditions presented in paragraph 11. Test section 2 used armor protection of 11-ton dolosse directly on the existing stone armor and was completely stable for both the 12-sec, 8.4-ft and 16-sec, 8.9-ft waves with no more than six dolosse rocking in place (Photo 9). Test section 3 (before testing, Photo 10) represented 2.0-ton dolos armor placed directly over the existing stone. The 12-sec, 8.4-ft and the 16-sec, 8.9-ft waves displaced a total of six dolosse from their initial position, readjusted the toe units, and showed moderate movement of dolosse below the swl. Even though there was some displacement and movement of dolosse, the overall section still provided protection and would be considered stable. Photo 11 shows the test section after testing with both the 12- and 16-sec wave conditions.

Conclusions

16. Based on the results of the hydraulic model tests described herein, it is conlcuded that for the range of wave conditions tested:

- a. Test section 1 or 1A will be an adequate repair section for breakwater sta 15+00 to 20+00.
- b. Test sections 2 and 3 will be adequate repair sections for breakwater sta 12+00 to 15+00 and sta 5+00 to 12+00, respectively.

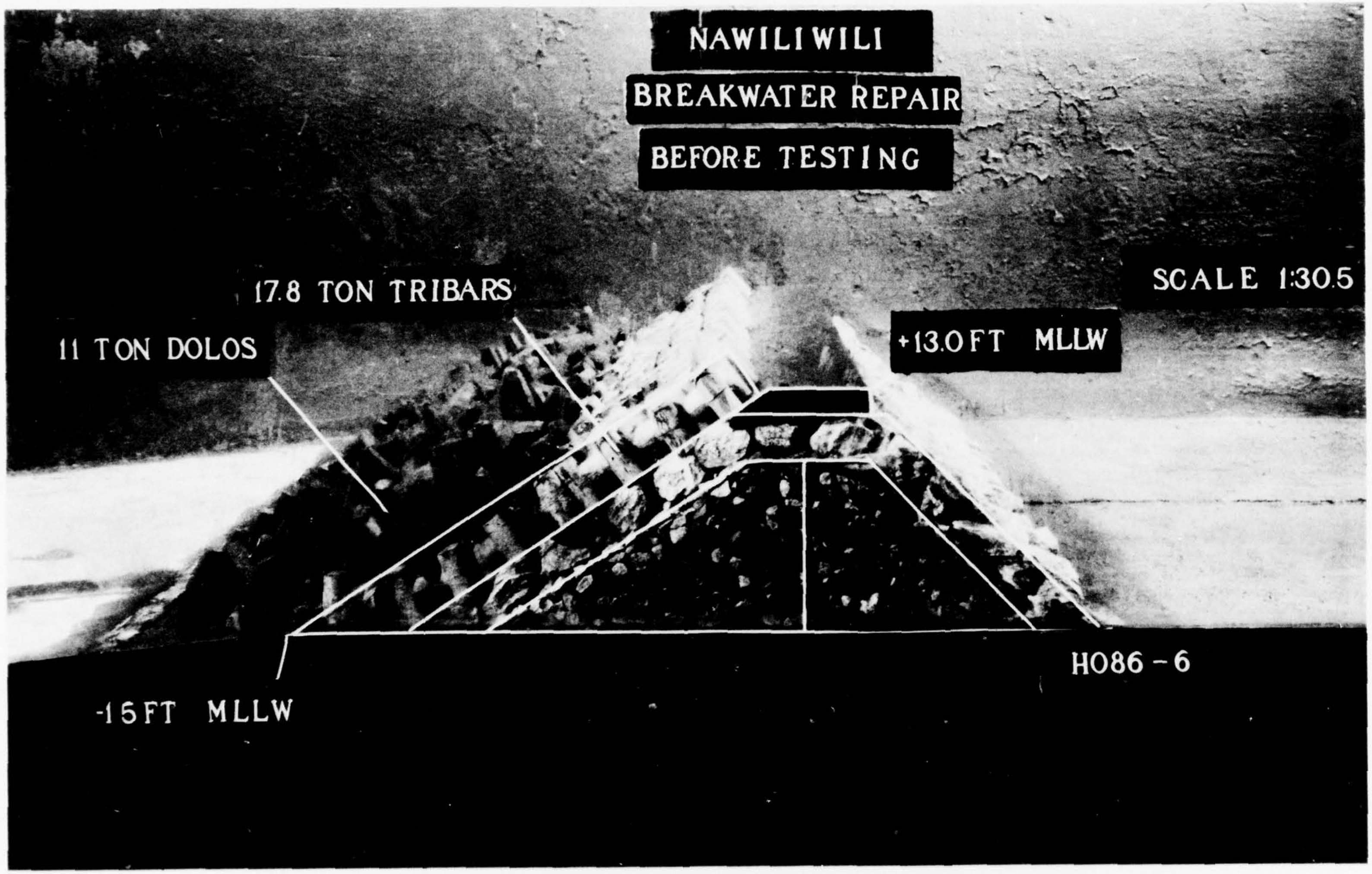

Photo 1. Side view of test section 1 before testing

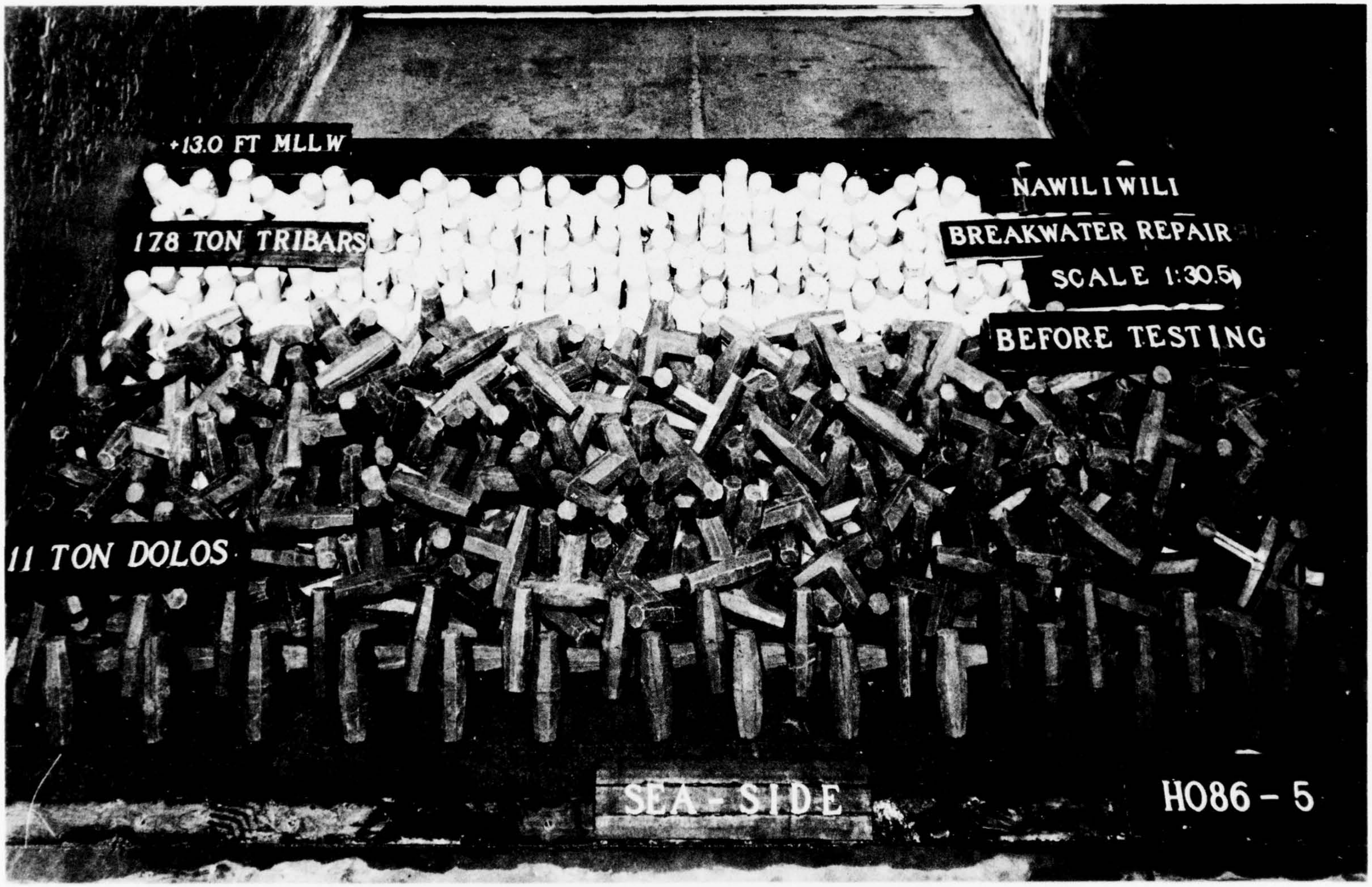

Photo 2. Sea-side view of test section 1 before testing

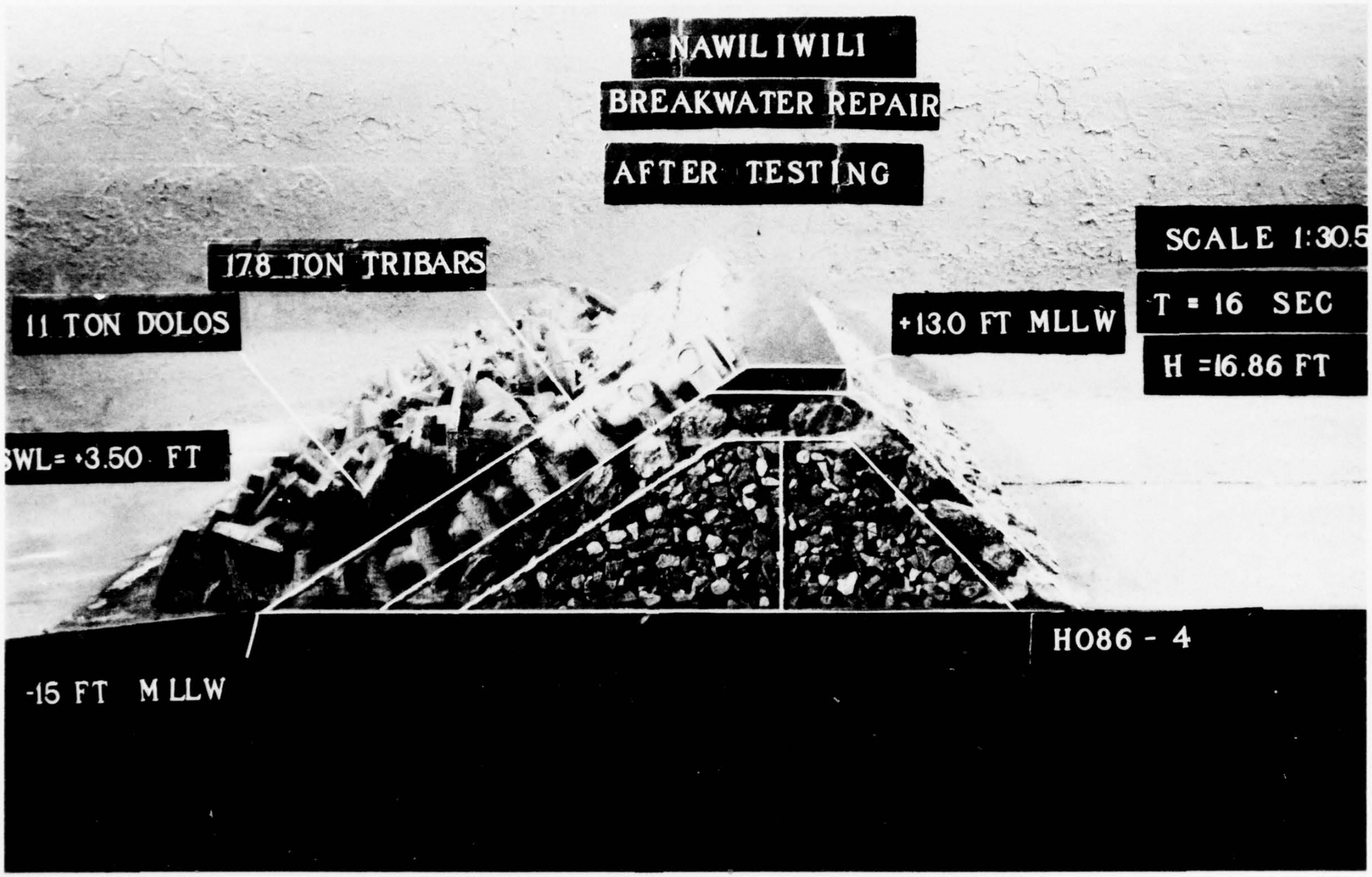

Photo 3. Side view of test section 1 after testing with 16-sec, 16.9-ft wave at +3.5 ft mllw swl

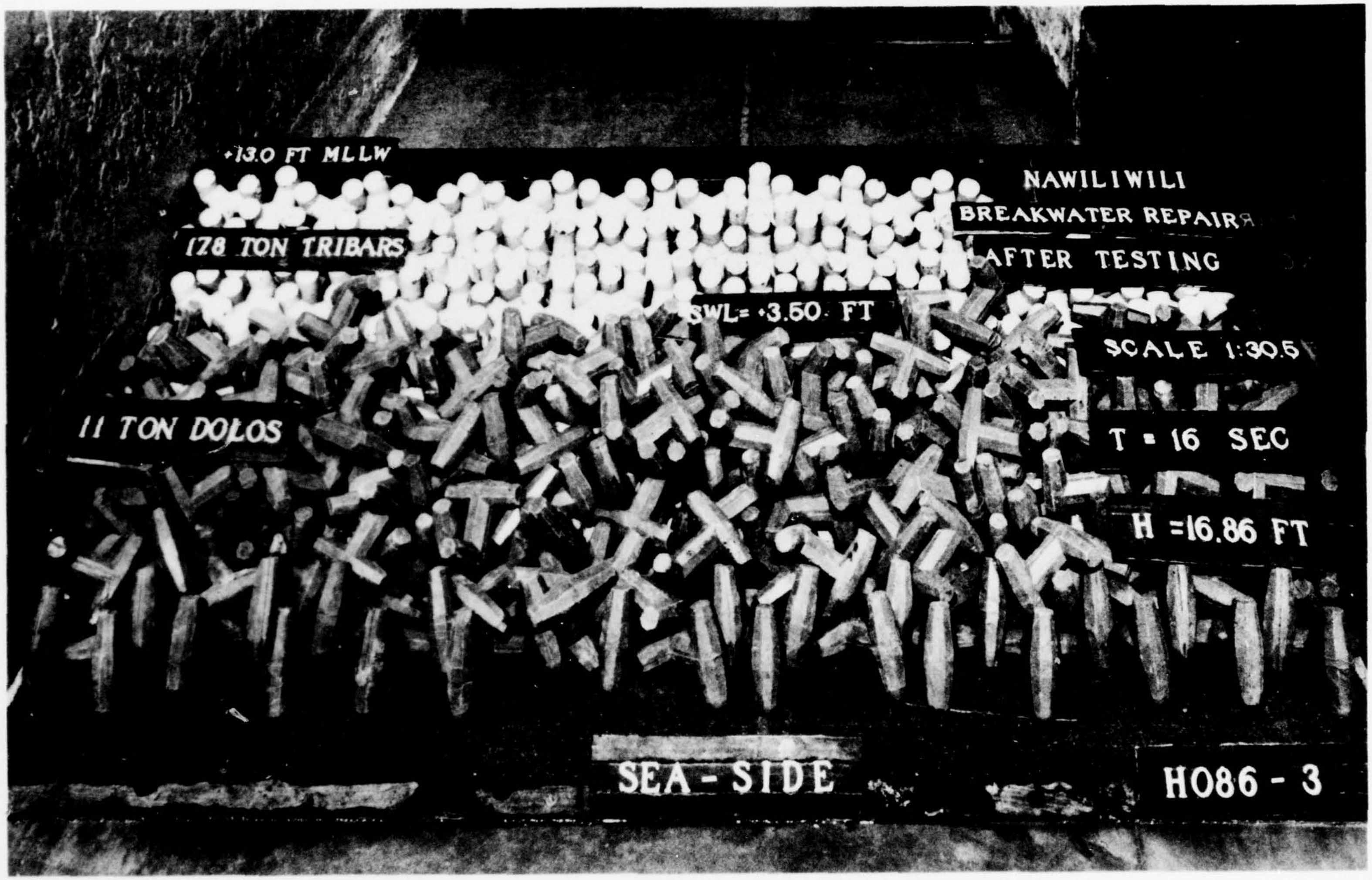

Photo 4. Sea-side view of test section 1 after testing with 16-sec, 16.9-ft wave at +3.5 ft mllw swl

Photo 5. Sea-side view of test section 1 after testing with 16-sec, 8.9-ft and 12-sec, 8.4-ft waves at -5 ft mllw swl

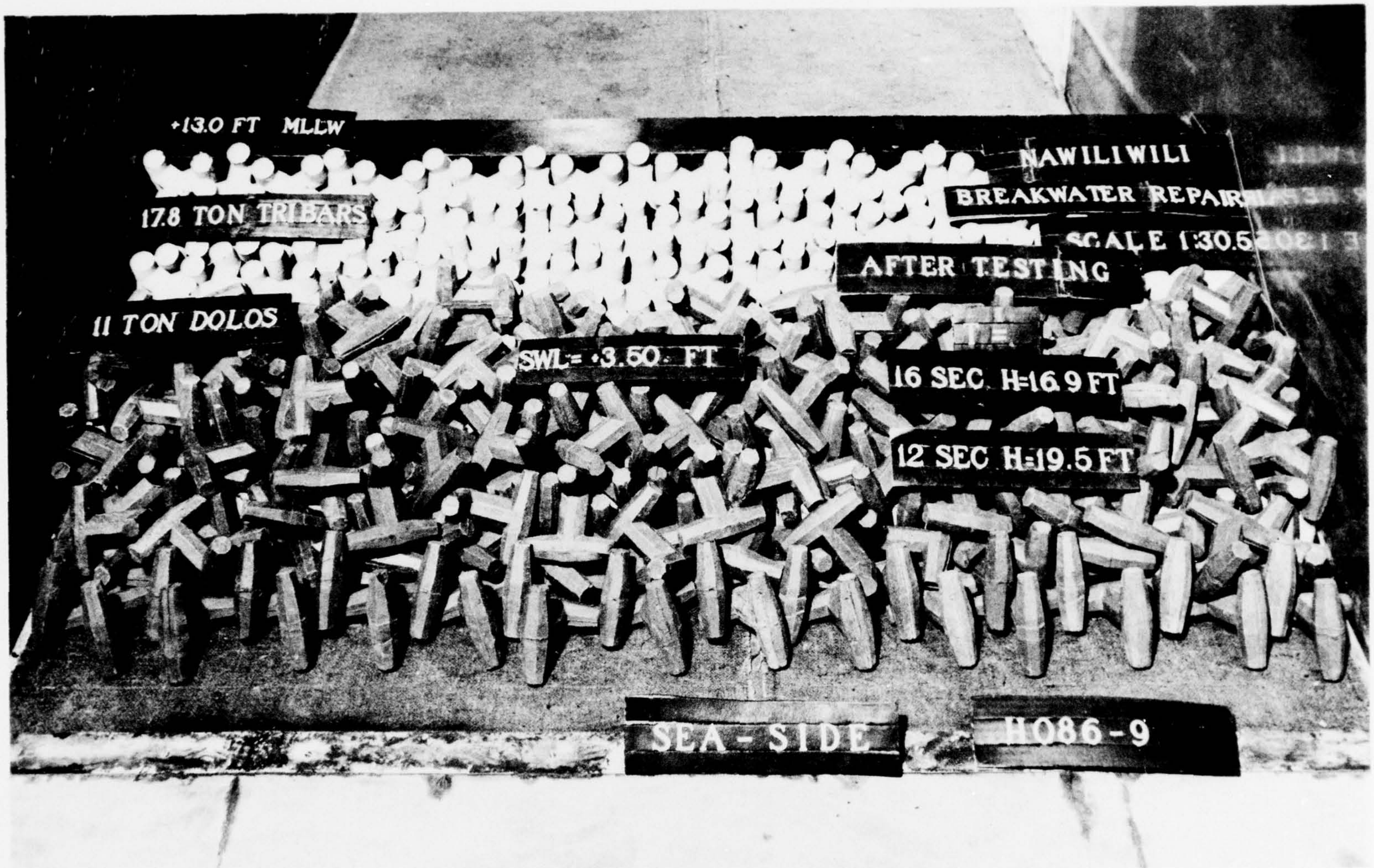

Photo 6. Sea-side view of test section 1 after testing at the -5 ft mllw swl and followed by 16-sec, 16.9-ft and 12-sec, 19.4-ft waves at +3.5 ft mllw swl

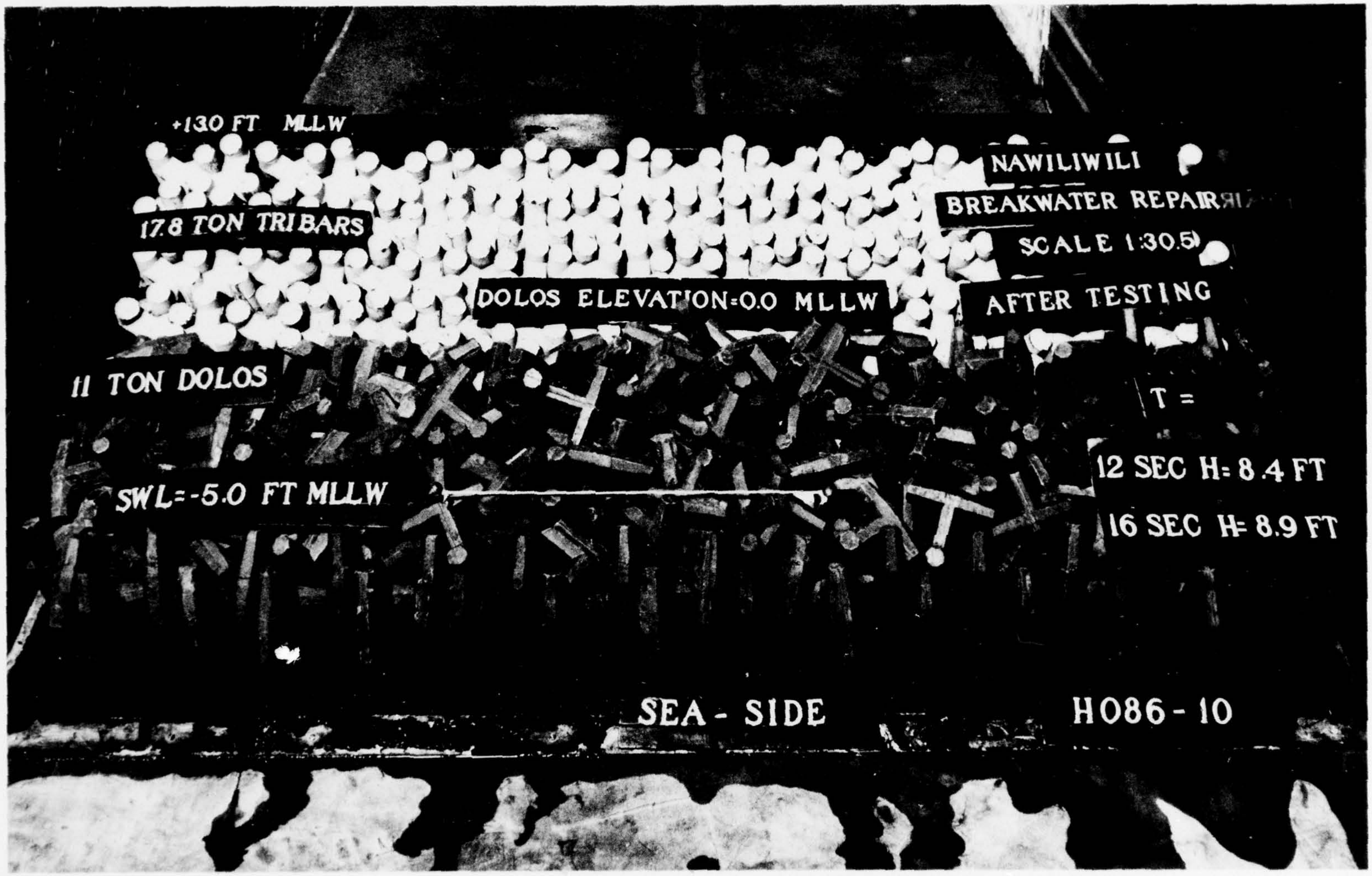

Photo 7. Sea-side view of test section 1A after testing with 12-sec, 8.4-ft and 16-sec, 8.9-ft waves at the -5 ft mllw swl

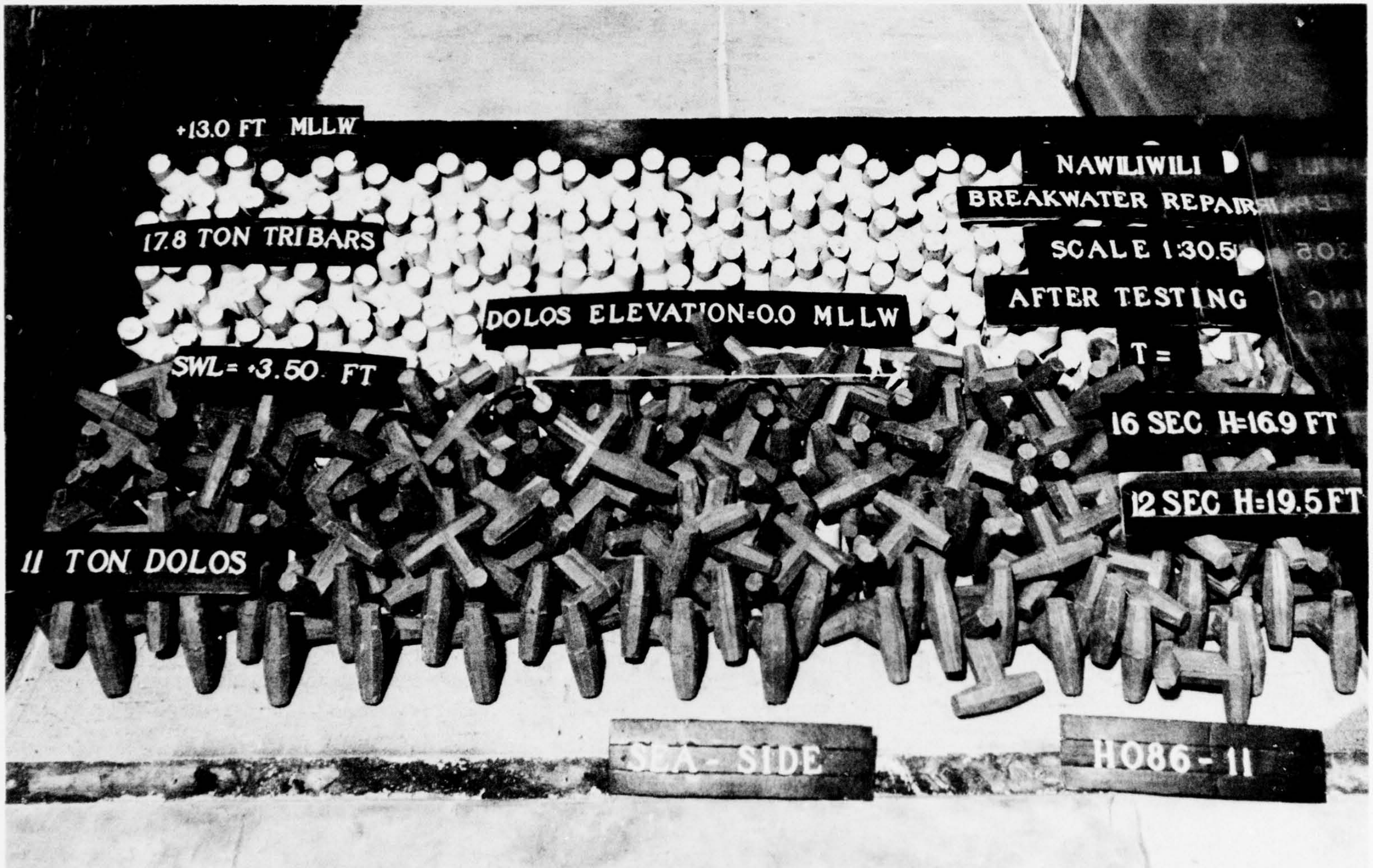

Photo 8. Sea-side view of test section 1A after testing with 16-sec, 16.9-ft and 12-sec, 19.5-ft waves at the +3.5 ft mllw swl

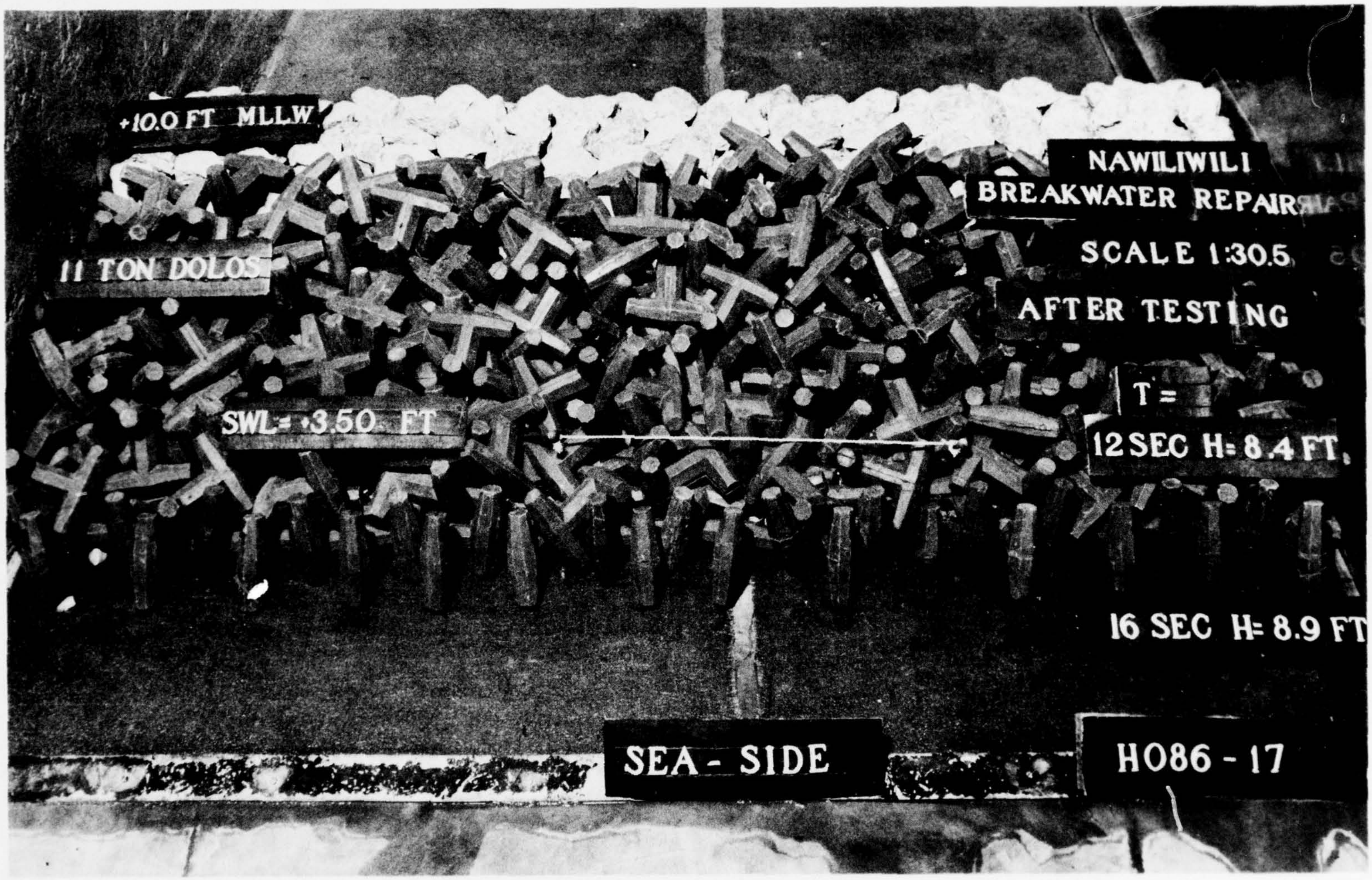

Photo 9. Sea-side view of test section 2 after testing with 12-sec, 8.4-ft and 16-sec, 8.9 ft waves at the +3.5 ft mllw swl

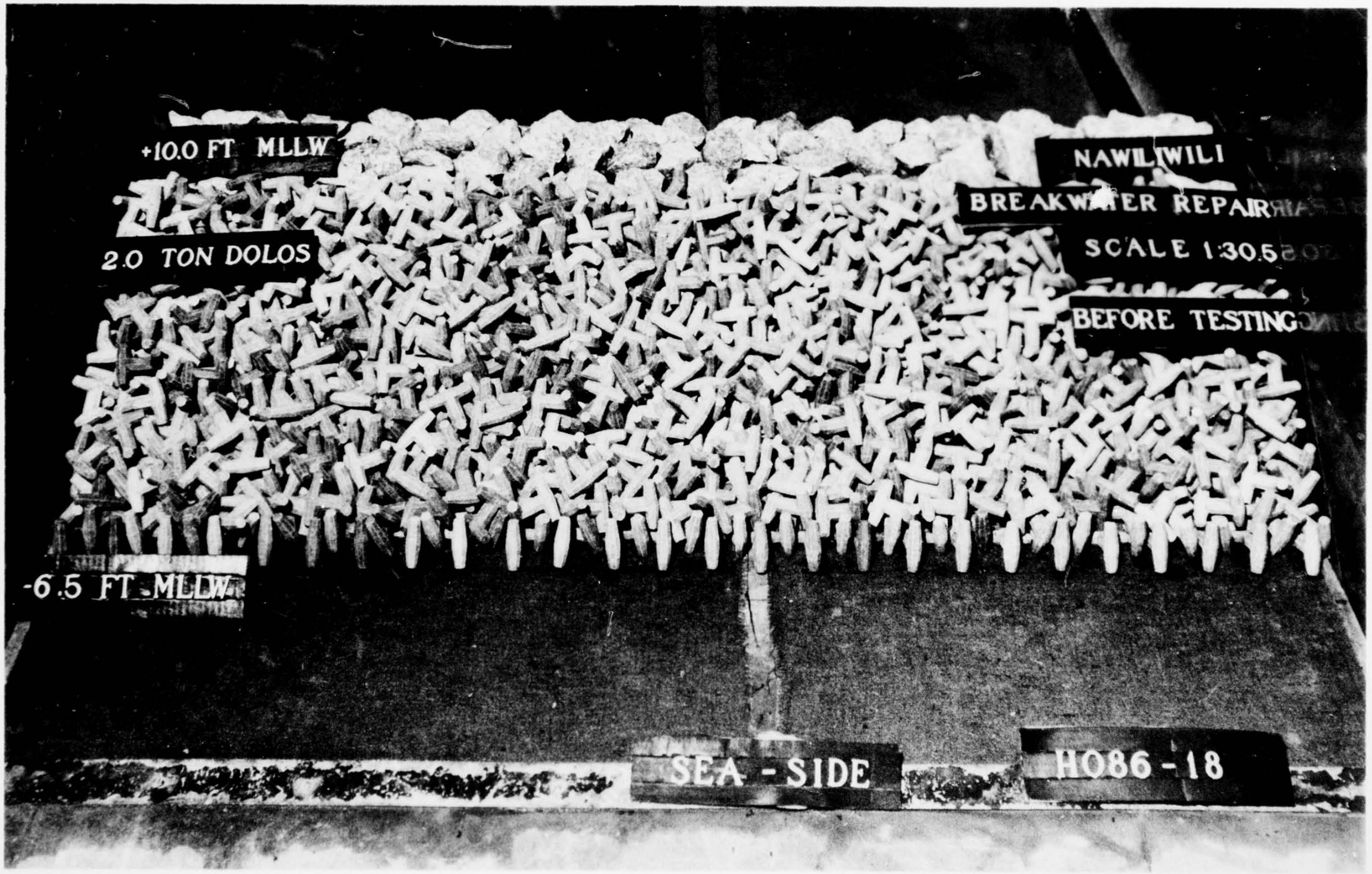

Photo 10. Sea-side view of test section 3 before testing

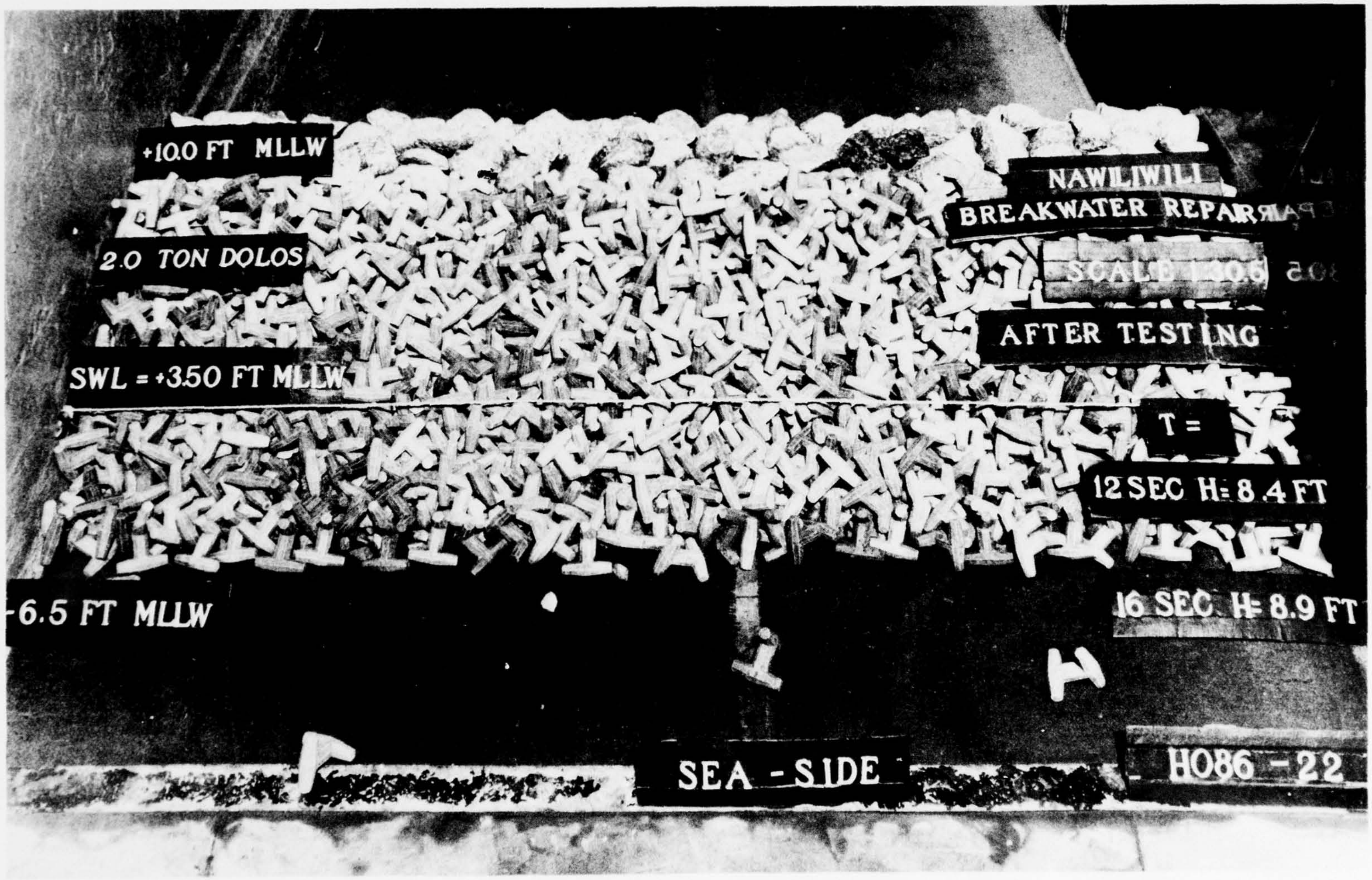

Photo 11. Sea-side view of test section 3 after testing with 12-sec, 8.4-ft and 16-sec, 8.9-ft waves at the +3.5 ft mllw swl

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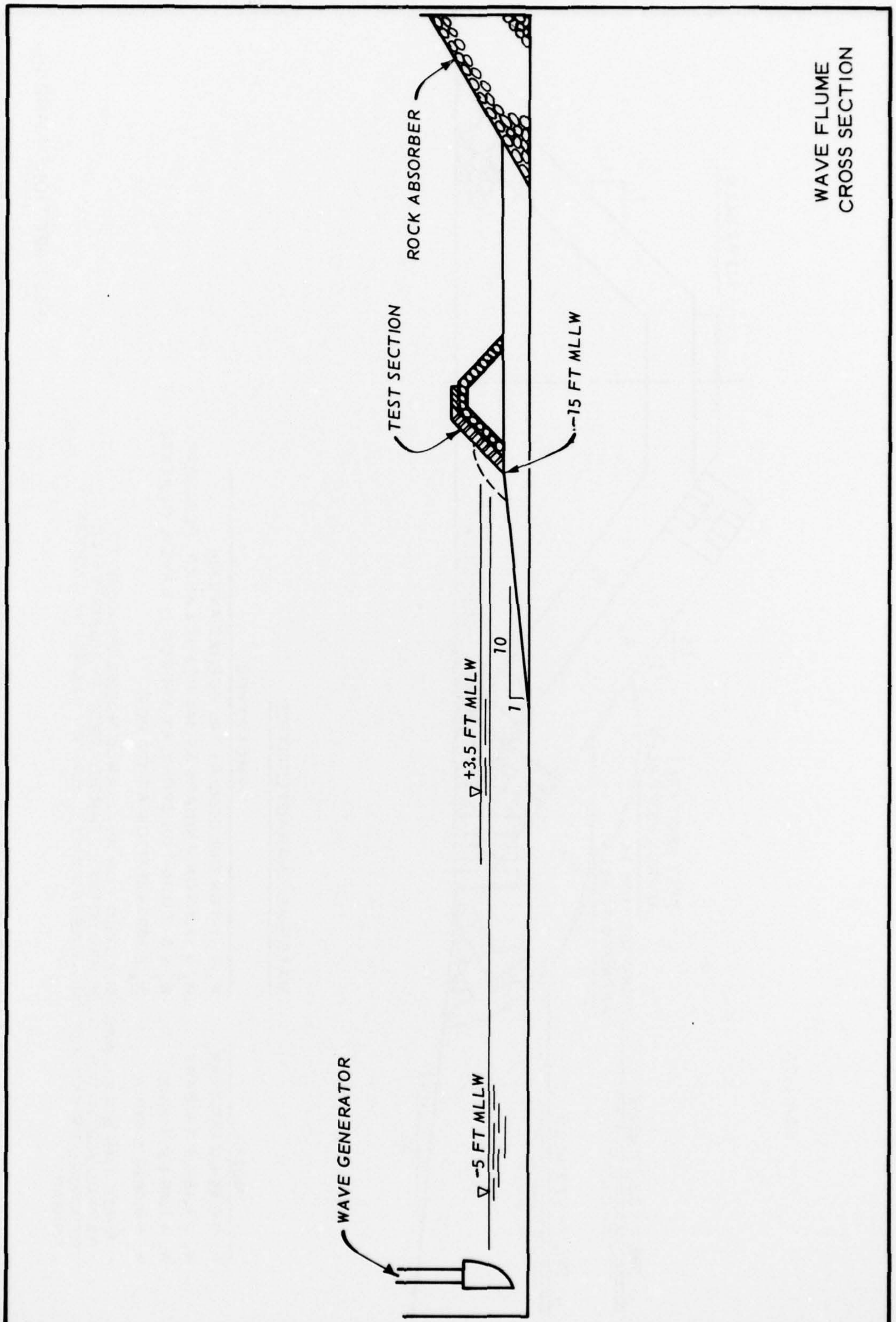
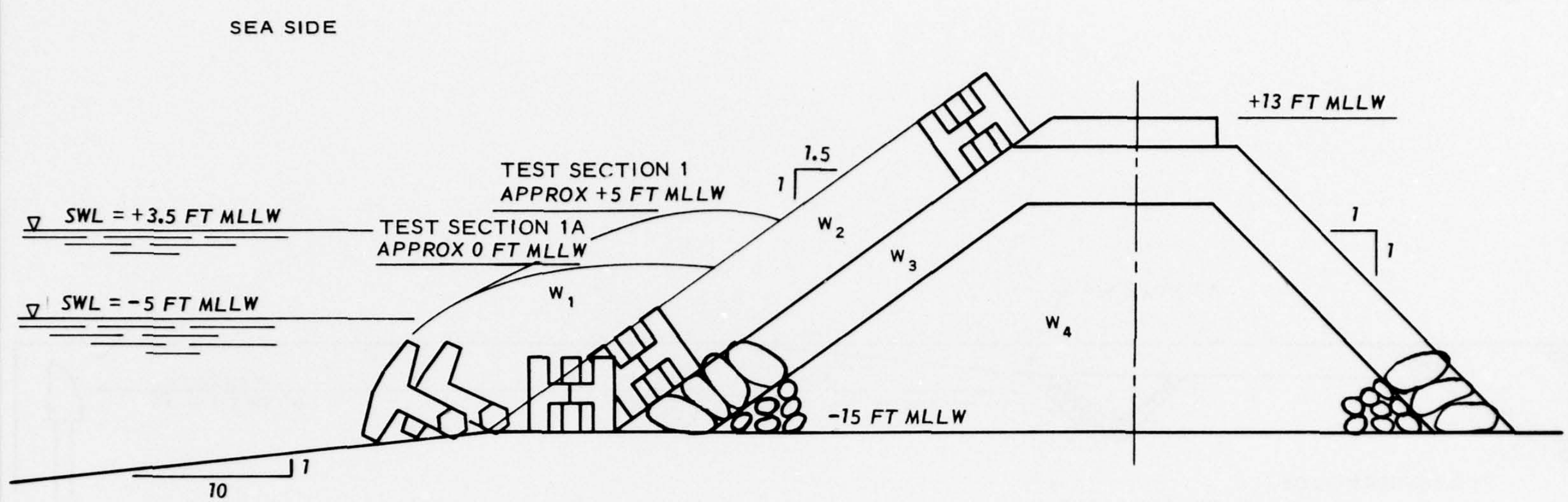


WAVE FLUME CROSS SECTION

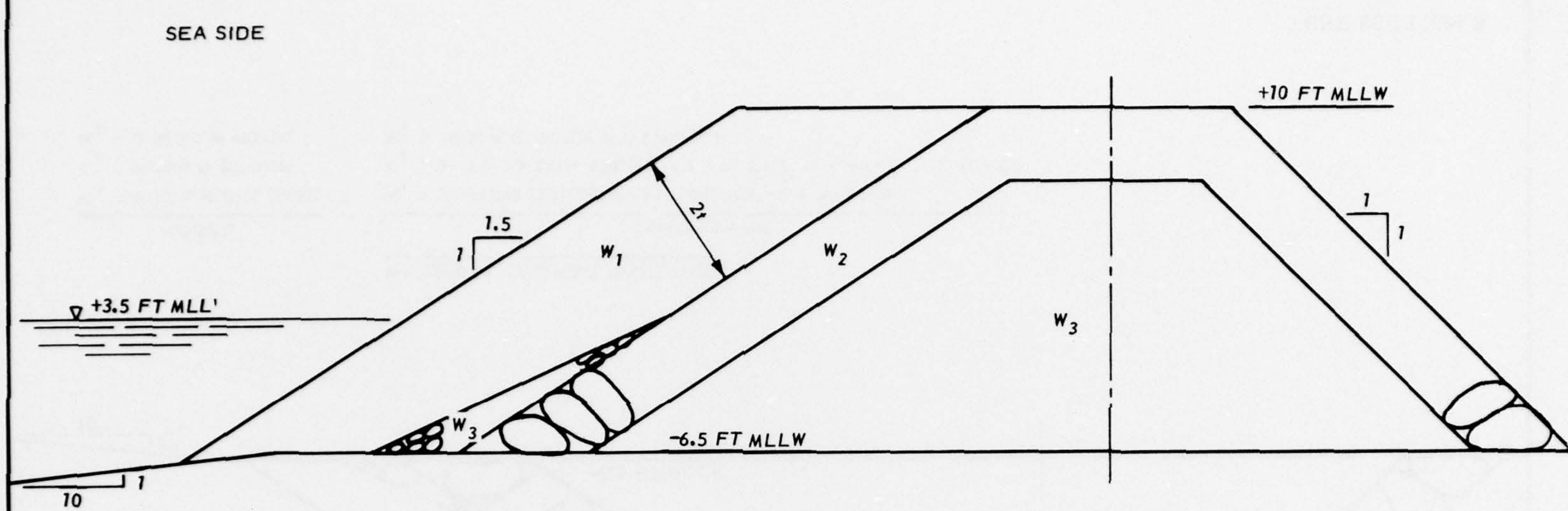


MATERIAL CHARACTERISTICS

MODEL	PROTOTYPE
W_1 = 0.86-LB DOLOSSE	W_1 = 11-TON DOLOSSE AT 146 PCF (2 LAYERS)
W_2 = 1.15-LB TRIBARS	W_2 = 17.8-TON TRIBARS AT 146 PCF (1 LAYER, PLACED)*
W_3 = 0.68-LB STONE	W_3 = 8- TO 10-TON STONE AT 174 PCF (1 LAYER, PLACED)
W_4 = 0.063-LB ROCK	$W_4 \leq$ 1800-LB ROCK AT 170 PCF

* SINCE THE MODEL WAS SELECTED FOR AVAILABLE MODEL DOLOSSE TO REPRODUCE 11-TON DOLOS PROTOTYPE, THE NEAREST AVAILABLE SIZE OF MODEL TRIBAR ACTUALLY REPRODUCED 16.1-TON IN LIEU OF 17.8-TON TRIBARS.

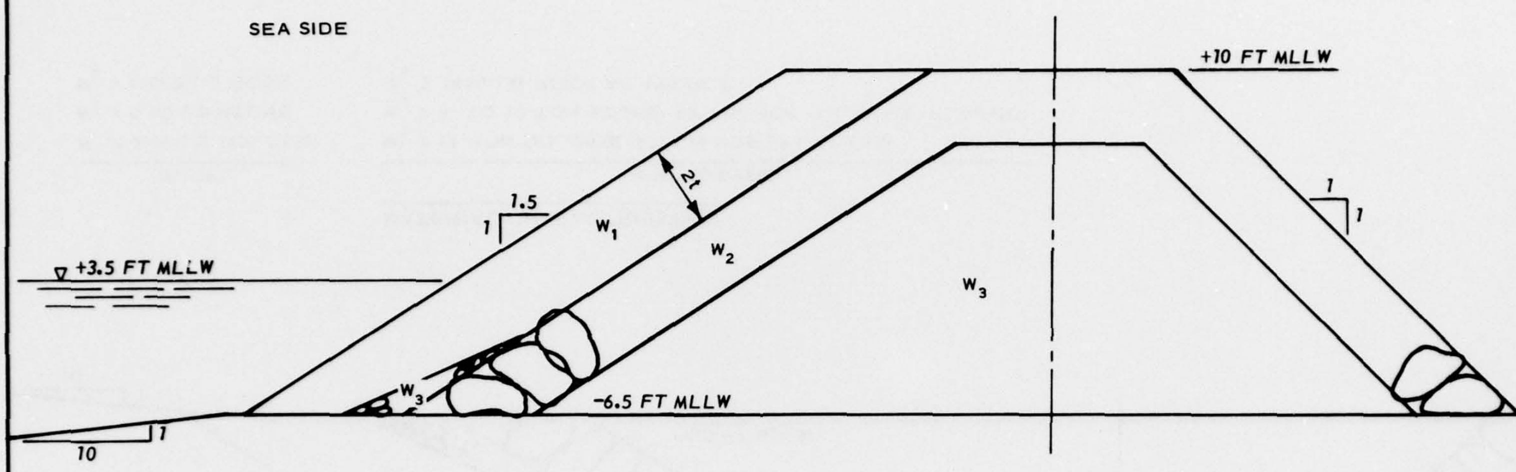
TEST SECTIONS 1 AND 1A



MATERIAL CHARACTERISTICS

MODEL	PROTOTYPE
W_1 = 0.86-LB DOLOSSE	W_1 = 11-TON DOLOSSE AT 146 PCF (2 LAYERS)
W_2 = 0.68-LB STONE	W_2 = 8- TO 10-TON STONE AT 174 PCF (1 LAYER, PLACED)
W_3 = 0.063-LB ROCK	W_3 $\leq$ 1800-LB ROCK AT 174 PCF

TEST SECTION 2



MATERIAL CHARACTERISTICS

MODEL	PROTOTYPE
W_1 = 0.15-LB DOLOSSE	W_1 = 2.0-TON DOLOSSE AT 146 PCF (2 LAYERS)
W_2 = 0.68-LB STONE	W_2 = 8- TO 10-TON STONE AT 174 PCF (1 LAYER, PLACED)
W_3 = 0.063-LB ROCK	$W_3 \leq$ 1800-LB ROCK AT 170 PCF

TEST SECTION 3

Appendix A: Notation

A_r	Area ratio (model to prototype)
H	Wave height, ft
k_Δ	Experimentally determined coefficient that is a function of the shape of the armor unit and the method of placement
L_m/L_p	Linear scale of the model
L_r	Length ratio (model to prototype)
subscript m	Model values
N_r	Required number of armor units for a given surface area
subscript p	Prototype values
P	Porosity of the cover layers, percent
S_r	Specific gravity of an individual armor unit or rock relative to the water in which the breakwater is constructed ($S_r = \gamma_r/\gamma_w$)
t	Thickness of n layers of armor units
T	Wave period, sec
V_r	Volume ratio (model to prototype)
W_r	Weight of an individual armor unit or rock, lb
γ_r	Specific weight of an individual armor unit or rock, pcf
γ_w	Specific weight of water, pcf

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Davidson, D Donald

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